# PROPOSAL FOR

# DOCTOR OF ENGINEERING

# WORK IN FLUID CONTROLS

SIR GEORGE WILLIAMS UNIVERSITY

FACULTY OF ENGINEERING

MEMORANDUM

TO: DEAN J. BORDAN

FROM: M. P. du PLESSIS APRIL 19/68.

SUBJECT: DOCTORAL WORK IN FLUID CONTROLS.

GENERAL:

The research area of Fluid Controls should be considered among the first within the Faculty of Engineering as an area to undertake Doctoral studies. As outlined in the notes of December, 1967 to Dr. J. M. Roxburgh of NRC (Appendix A), considerable interest exists in the Faculty for research in the

That area has been developed over the last 1 1/2 years at Sir George Williams University. It is an attractive area in that it takes realistic account of the local academic and industrial environment in the following ways;

1. It is consistent with the emphasis placed on mechanical and electrical systems in the existing undergraduate and graduate courses and laboratory facilities and it reflects the research interests of a number of faculty members.

2. It avoids unproductive duplication of other research efforts in Canada, and, in particular in local research institutions.

3. It complements development work conducted by a local R and D laboratory, thus enabling all participants to benefit from the possible pooling of human and physical resources and the formation of a strong research team.

Consistent with this interest we have made a major commitment to the area of Fluid Controls during the last 1 1/2 years as follows;

1. To date, four faculty members, with considerable experience in the direction and teaching of graduate students, have a direct interest in this research area. Since September, 1967 two full-time research associates have been working on specific projects in this area (See Curriculum Vitae). These topics are described in Appendix B under the headings:

a) Investigation of turbulent noise in fluidic devices.
b) Transmission line modelling and matching.

One of our laboratory demonstrators, registered as an M.Eng student, has been hired as a research assistant in this area during the summer months, starting May, 1968.

2. The required instrumentation for research work in this area has been purchased (See Appendix B). A separate research laboratory with the necessary services and four office cubicles, etc. has recently been completed (see Appendix B).

3. A close liason exists with Aviation Electric Limited (in Montreal), the Canadian company chosen and supported by NRC to develop fluidic components and systems. For instance, they permitted the use of their library for our initial literature search; and, at present, they are seeking additional financial support for our research program through the Industrial Research Assistance Programme.

4. A close liason exists with the newly formed fluidics group at NRC. For example, they have undertaken to build special research components for us, and they invited our research team members to participate in special projects in their laboratories. Recently, they sponsored one of our research associates to a Fluidics Conference in Toronto. (See letter to J.C.C., Appendix D)

## ANSWERS TO SPECIFIC QUESTIONS RAISED BY THE BOARD OF GRADUATE STUDIES

### a) Specific Faculty Members Involved

The faculty members involved in graduate studies in the Fluid Controls area are:

W. M. Mansour
M. P. du Plessis
J. C. Callaghan
G. K. Fleming

(Appendix E contains the curriculum vitae of the Faculty Members. Table I summarizes their activities.)

TABLE I

## SUMMARY OF ACTIVITIES OF FACULTY IN FLUID CONTROLS

| No. | Name | Age | Highest Degree | Experience in Guiding Graduate Students | Experience in Teaching Graduate Courses | Publications (Papers and Conferences) | Patents (Granted and/or Filed) | Books | NRC Support (Current) | R and D Experience | Professional Consultant |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mansour | 37 | Ph.D. Toronto | 1-Ph.D. 4-Master | Yes Carleton | Classified | - | 1 (M) | $2940 | N.E.-Summer UACL-1 1/2 Yr | UACL |
| 2 | du Plessis | 35 | Ph.D. Alberta | - | - | 3 | 3 | - | $5340 | Imperial Oil 5 Yrs | Dominion (G.E.) |
| 3 | Callaghan | 35 | M.S. M.I.T. | 3-Master | Yes N.S.T.C. | 7 | 2 | - | $7350 | N.E.-Summer F.C.L.- Summer | F.C.L. Dupont |
| 4 | Fleming | 35 | Ph.D. Waterloo | 1-Master | Yes Sherbrooke | 4 | - | - | | | Design Inst (Waterloo) |

### OTHER FACULTY IN RELATED AREAS

| | | | | |
|---|---|---|---|---|
| 5 | Tari | 27 | Dr.- Paris | Automatic Controls |
| 6 | Dent# | 35 | Ph.D. Lough-borough | I.C. Engines and Gas Turbines (Gasdynamics) |
| 7 | Pannuska# | | Ph.D. (Oxon) | Digital System Control |
| 8 | Kim# | | Ph.D. | Circuit Theory |

### SUPPORTING RESEARCH PERSONNEL

| | | | |
|---|---|---|---|
| 9 | Suresh | M.S. | Research Associate |
| 10 | Vrana | B.Sc. | Research Associate |
| 11 | Tsang | B.Eng | Research Assistant |

# Has not yet accepted position.
(M) Manuscript-Available from Carleton University Bookstore.
See Appendix E for curriculum vitae.

### NRC SUPPORT HISTORY

| Years | 1 | 2 | 3 |
|---|---|---|---|
| 1968/69 | $2940 | 5340 | 7350 |
| 67/68 | N.A. | 4600 | 3000 |
| 66/67 | 60,000 | 5000 | 4000 |
| 65/66 | | N.A. | 4000 |
| 64/65 | N.A. | N.A. | 3000 |

### R and D Experience

1. Presently directing the activities of several engineers with advanced degrees.
2. Directed the activities of 3 engineers with advanced degrees (2 Masters, 1 Ph.D.) and 2 Faculty members (during summers).

It should be noted that Professors Callaghan and du Plessis are presently directing the activities of the two research associates in the area. Also Dr. Mansour has directed a Ph.D. candidate while at Carleton University on the topic of jet interaction, a problem of vital interest in fluid control. The Doctoral dissertation of Prof. Fleming was the "Analysis of Incompressible Curved Jet Flow in Control Elements".

It is proposed that the first Doctoral candidate/s be guided by Professors Mansour, Callaghan and du Plessis, and that the teaching duties of each be reduced to a maximum of 8 contact hours per week. This can be effected for 1968/69 as shown in Table 2.

TABLE 2

| | FIRST TERM | SECOND TERM |
|---|---|---|
| Mansour | Numerical Methods in Eng. Syst. I (Grad 3) | Numerical Methods in Eng. Syst. II (Grad 3) |
| | Phys. Syst. and Meas. I (E 372.1 - 3,3) | Control Syst. Des. ( - 3,1 1/2) |
| | Total (6,3) | Total (6, 1 1/2) |
| Callaghan | Phys. Syst I (Grad 3) | Fluidics (1/2 Grad 3) |
| | Phys. Syst and Meas. II. (E 471.1 - 3,3) | Phys. Syst. and Meas. I (E 372.2 - 3,3) |
| | Total (6,3) | Total (4 1/2, 3) |
| du Plessis | Adv. Fluid Mech. (Grad 3) | Fluidics (1/2 Grad 3) |
| | Gasdynamics M.E. 55.1 - 3, 1/2 of 3) | Fluid Machinery (M.E. 553.2 - 3, 1/2 of 3) |
| | Total (6, 1 1/2) | Total ( 4 1/2, 1 1/2) |

In order to achieve these reduced teaching loads, it will be necessary to reduce by one course the number of elective courses available to 5th year engineering students and some re-allocation of teaching assignments. The elective course not offered will be influenced by student demand.

b) Effect on Undergraduate Programme

The only negative effect on the undergraduate programme is the reduction by one course the number of available electives in the 5th year. The original Doctor of Engineering proposal, on Page 9, noted the positive effects.

c) Graduate Student Support

The Faculty members working in the area have NRC operating grants for 1968/69 totalling $15,630. One of the laboratory instructors, Mr. Tsang, has chosen Fluid Controls as his research area for his M. Eng programme. It should be noted that his excellent undergraduate record would no doubt make him eligible for Doctoral studies.

d) Research Costs, Space, Equipment, etc.

The facilities required to pursue research in the area of fluid controls are;

i) Research Laboratory
ii) Considerable Specialized Instrumentation
iii) Simulation Equipment
iv) Library
v) Student Desk Space
vi) Digital Computer

As noted earlier in this document in the Appendices A and B, and in the original Doctor of Engineering Proposal, all of the above, except item iv) (Library - which is assessed below in Part e), has been planned for and presently exist in a form suitable for efficient research in Fluid Controls.

e) Disposition of Available Library Funds

As noted in the Doctor of Engineering proposal of March 29,1968 two sections of the library need improvement in the Fluid Controls area, namely the acquisition of a selected list of Research Progress Reports and the addition of a few subscriptions to the present list of Journal holdings. These are detailed below. Appendix F lists the major journals in Fluids, Controls and Instrumentation, and those without an asterisk identify our holdings.

1. Research Progress Reports;

* Proceeding of joint Automatic Control Conferences 1966 (7th Conf).

Moncgraphs of the U.S. National Bureau of Standards No. 67. 1963.

* Technical notes of the National Bureau of Standards.

* U.S. Patent Gazette.

* American Society for Artificial Internal Organs, Georgetown U. Hosp., Washington, D.C., 1966.

M.I.T. Laboratory Reports.

* NASA CR series.

* NASA TND series.

* R.A.E. Technical Reports (Gt. Britain).

* Ejectors and Mixing of Streams - RAE Bibliography 6, November 1964, AGARD, Paris.

* NASA - TM-X Series (TM-X-52120, 1965).

Franklin Institute Res. Labs, for Harry Diamond Labs, US Army Mat'l Comm.

* Fluidonics Research Lab (Div. of Imperial Eastman, Salt Lake City, Utah), Reports.

* Bowles Corporation Reports.

* Giamini Reports.

* Bendix Corporation Reports.

Fluid Control Systems Seminar, Penn. State University, 1965. (IBM Report on switching).

Sperry Engineering Review, 1963, with gaps.

Those without an asterisk are available.
Priority should be given to obtain those with an asterisk. These can be obtained at no cost, or on an "interchange" basis.

2. Additional Subscriptions to Journals required:

The acquisition costs of the journals required is presently being determined by the library. The present library agreements and the continued cooperation with AEL will ensure library facilities for research in Fluid Controls.

f) Others

The minimum viable level of activity in Fluid Controls would be the Faculty members directly involved and one Doctoral student. It should be noted that when the student numbers are very small the student benefits by close association with his faculty supervisors. The relationship between faculty and student resembles that of an apprenticeship. This relationship is a substitute for the educational value derived from the interchange of ideas within a group of Doctoral students which is the normal situation at the larger Universities. The present group could supervise up to 7 students with only the incremental cost associated directly with the support of the candidates.

The present concentration of faculty in Fluid Controls is consistent with our policy within the Faculty of Engineering of developing teams in certain research areas.

# APPENDIX A

# SIR GEORGE WILLIAMS UNIVERSITY

## FACULTY OF ENGINEERING

NOTES TO DR. J. M. ROXBURGH OF NRC - SUBSEQUENT TO HIS VISIT TO THE FACULTY OF ENGINEERING, OCTOBER 31st, 1967.

These notes are a reminder of some of the discussions between Dr. J. M. Roxburgh and some members of the Faculty of Engineering, with regard to the Faculty's research potential and plans, and its special needs.

### A. BACKGROUND OF ENGINEERING AT SIR GEORGE WILLIAMS UNIVERSITY

In 1957, a three-year Certificate of Engineering programme, in both Day and Evening Divisions, was started. Students completed their B.Eng. at other Universities, most notably at McGill. In 1966, our course offerings were extended to include the last two years of the B.Eng. programme in the Day Division only; the first Bachelors candidates will therefore graduate in May, 1968.

Concurrent with this extension of the programme, new classroom and Laboratory space became available in the new Henry F. Hall Building. The University committed capital funds for new equipment in all the Engineering laboratories. The fourth-year laboratories were completed in 1966-67 and, at present, all of the fifth-year laboratories are nearing completion.

A programme is offered in three professional areas; Civil, Electrical and Mechanical Engineering. Some of the main features of the curriculum are:

1. A student can elect to take a fairly conventional programme in the above professional disciplines.

2. All students take an integrated three-term sequence in Physical Systems and Measurements, starting in the third-year of the five-year programme.

3. Electrical and Mechanical students can further elect a sequence of courses in the Systems area to permit study in considerable depth.

To illustrate the particular emphasis, the Systems-related courses available in the undergraduate curriculum are listed below:

| | |
|---|---|
| Second Year: | Digital Computer Programming. |
| Third Year: | Two half-courses of a compulsory three-term sequence in Physical Systems and Measurements. These courses include a comprehensive series of special laboratory experiments designed to emphasize the application of systems concepts in Engineering measurements, and include instruction in analog simulation. |
| Fourth Year: | The compulsory physical systems sequence is concluded in the first term. In the second term, other courses in the Systems area are: Linear Feedback Theory and Network Analysis. |
| Fifth Year: | Additional elective courses available include: Non-Linear Control Theory, Computer Organization and Software, Control System Design, Advanced System Theory, Digital Computers in Systems. |

It is hoped to make full use of a sophisticated Analog and Hybrid Simulation facility in these and related courses.

A Master of Engineering programme will start in May, 1968. This programme is unique in Canada in that it has no full-time residence requirement, and is offered exclusively to practicing Engineers, on a part-time basis. This Evening M.Eng. programme is in keeping with the historic commitment of Sir George Williams University to the needs of continuing education. The degree requirements are flexible, permitting a wide variation in the number of dissertation "Credits", from a conventional thesis to, essentially, a major report with additional complementary course work. For most students, work for the dissertation will be undertaken at the University, however, candidates engaged in suitable research, design, and development work in their full-time employment, will be encouraged to arrange for agreement among employer, faculty and the University for submission of a dissertation based upon that work, provided appropriate supervisory arrangements can be made.

By special arrangement, it is possible for students to register for graduate courses offered in the Extension Department of McGill University, as part of their work at Sir George Williams University.

To date, the programme has been enthusiastically received. During its development, discussions were held with representatives from local industry and they encouraged it strongly. The response to a refresher course in Mathematics is a measure of its acceptance by the local Engineers. At present, twenty-five Engineers are enrolled, and most of them intend to continue to the Master of Engineering programme when it commences next spring. Some three hundred Engineers have requested further information. A total of approximately fifty candidates have already submitted applications.

Faculty strength has increased concurrently with the development of the undergraduate programme; eighteen full-time appointments have now been made, plus eight sessional and part-time appointments. Next year six additional full-time appointments are planned. Up to now, much faculty effort has been directed towards the development of the undergraduate curriculum and the new laboratories; at present, more attention is being concentrated on formulating graduate programmes as well as developing a research policy for the Faculty.

Supporting technical personnel are:

(a) Seven Technicians, (2 Machinists, 2 Electrical Technicians, 1 Mechanical Technician, 1 Civil Technician and 1 Mechanic's Helper).

(b) One Simulation Engineer.

(c) Two Research Associates.

Supporting services include a time-sharing CDC 3300 Digital Computer with a remote console in the Engineering Simulation Laboratory, and a well-equipped Machine Shop. Approximately $ 750,000 of Laboratory equipment have been purchased over the last two years with many of these items having specific research capability. (See List in Section C).

Planning is now underway for a full-time Doctor of Engineering programme, in which applied, rather than theoretical, research will be emphasized.

## B. POLICY FOR RESEARCH GROWTH

We believe that it is necessary for a young Faculty to operate within a Research Policy which has the broadest possible faculty acceptance. The definition of such a Policy must take realistic account of the local academic and industrial environment, and of the manner in which most effective use can be made of existing and potential human and physical resources within this environment.

At present our commitments to undergraduate and graduate teaching are in the three professional disciplines of Civil, Electrical and Mechanical Engineering. Our curriculum evolved from a recognition of the unifying nature of the systems approach when applied to these disciplines. Our faculty members have accepted this systems commitment, and much of our research activity should therefore also reflect it.

Since our graduate programme is directed to practising professional engineers who wish to acquire advanced degrees on a part-time basis, our research

efforts should, ideally, reflect the research and development interests of local industry. When University research complements development work conducted by local industry, the possible pooling of human and physical resources should provide mutual benefit to all participating bodies. We are hopeful of direct financial support from industry if our own resources are known and available for the solution of industrial problems.

We believe that in order to make effective use of our resources we should attempt to avoid proliferation of unrelated research projects; but rather, concentrate effort on the development of strong research teams in a few areas. This should then provide necessary continuity for particular research endeavours. Implicit in this is the gathering of research staff (faculty, research associates, and technicians), with expertise in the selected areas, together with the best equipment and supporting services.

The selected research areas should avoid unproductive duplication of other research efforts in Canada, and, in particular, of activity in local research institutions.

The choice of areas of concentration must take into account the constraints implied above, but should not inhibit the pursuit of research activities by individual faculty members whose personal background and teaching interests do not naturally mesh with the more general interests of a larger group. Such faculty must be free to seek support for projects outside the larger group activities and will receive internal assistance to the extent possible.

The Research Policy of the Engineering Faculty is, then, to concentrate support in a few well defined areas involving research team effort, primarily on projects related to industrial problems and preferably complementary to local research and development programmes.

## C. REVIEW OF RESEARCH DEVELOPMENT TO DATE

In accordance with our Policy, a number of research areas are being developed within the three Departments, and within the Faculty generally.

Considerable interest now exists within the Faculty for research in the areas of fluidics and simulation applications, in particular, hybrid simulation applications. These areas satisfy the constraints considered in Section B, and the Faculty of Engineering has now made a major commitment to these areas. A broad range of instrumentation for fluidics research has been acquired and two full-time Research Associates are working with faculty on specific projects. In the simulation area, the analog section (EAI 680) of a large hybrid facility (EAI 690) has been installed and many faculty members have defined projects which require its use. (Appendix A-1).

Aviation Electric Limited, the only Canadian manufacturer of fluidic components and systems, has been helpful to us in discussions on fluidics research and by permitting use of their library for an initial literature search. Also, it has offered assistance in constructing any needed models.

The undergraduate laboratory equipment and especially the instrumentation, were purchased with both teaching and research potential in mind. In particular, approximately $ 100,000 was allocated for setting up a hybrid simulation laboratory. After wide consultation, with, among others, Roland Gagné and Ed Funke of the NRC Analysis Laboratories, it was agreed that the wisest investment to meet the needs of undergraduate instruction and of increasing research activity would be to purchase an expandable facility - potentially a fully hybrid computer. The EAI 690 system appeared to represent the best value for our purpose and we therefore have installed the basic EAI 680 analog section with a view to expanding to the EAI 690 hybrid configuration at the earliest opportunity. The University has budgeted for a substantial portion of the total expansion cost; the remainder must be obtained from other sources. We are hopeful that NRC will favourably consider a request for adequate support in this area.

In other areas, our laboratories have been equipped with a great deal of instrumentation with research capability. It is perhaps worth listing some of these items:

A hot-wire anemometer with probes suitable for use in conductive and non-conductive media; an expandable 50 channel digital data logger; a multi-channel tape recorder; a high speed 16 mm movie camera; numerous items of display and recording equipment such as oscilloscopes with camera attachment, a multi-channel optical oscillograph, dual channel stylus oscillographs, X-Y recorders; and a great variety of transducers for force, pressure, displacement, acceleration, torque and temperature measurement.

The structures laboratory is expecting delivery of an expandable servo-controlled structural loading system for static and dynamic tests, for use on a large test-bed. (Similar to the NRC Building Research test-bed). The initial installation will include two channels with 20,000 and 50,000 lb. jacks. The Thermodynamics laboratory includes a free-piston engine in addition to more conventional equipment.

## D. CONTINUING SUPPORT FOR RESEARCH

Research activities will be supported in the following ways: by University Capital and Operating Funds, by Industry, by Research-Supporting Agencies such as NRC, and by contract research.

### University Support

The recent expenditures for equipping the Henry F. Hall Building have provided the impetus for a growing commitment to graduate studies and research at Sir George Williams University. Annual budgets include internal research funds and provision of continuing supporting facilities, such as the Digital Computer services, Technical staff and shops, and Library development. (The donation of the E.I.C. Library, jointly to Sir George Williams and Ecole Polytechnique, has provided a sharp increase in our Library resources).

## NRC Support

### Operating and Major Equipment Grants

As outlined at the October 31st, 1967, meeting, a sizeable number of operating grant requests have now been made, many of which include requests for a Professional Associate. (See Appendix A-2). In addition a Major Equipment Grant submission was made to defray costs associated with expansion of the simulation facility. (See supporting letter - Appendix B).

### Negotiated Development Grant

A major commitment has been made in the systems area in terms of course offerings in the undergraduate and graduate programmes, and Faculty strength is being concentrated commensurate with this commitment. As can be expected, a major part of the research activity of faculty will be directed towards problems in the physical systems area. To fully exploit this research interest and capability, additional equipment, research assistants, and faculty are needed. Discussions will be held with NRC in the near future to outline these requirements and to determine the assistance available from NRC under its Negotiated Development Grant Program.

## Contract Research and Industrial Support

Efforts will be directed to explore all possibilities for obtaining contract research and general industrial support. An Industrial Liaison Officer will be appointed at the earliest opportunity.

Jack Bordan,
J. Clair Callaghan,
M. P. duPlessis.

December, 1967.

# APPENDIX B

## 1. INTRODUCTION

In the past decade considerable progress has been achieved in the area of Fluidic control and instrumentation. Due to the early availability of fluidic digital devices, however, most of the developments fell into the general category of digital systems. The performance capability of present dry fluidic digital systems is very close to that of conventional hydraulic, mechanical, and electromechanical systems which have occupied a prominent position in industrial control applications. In contrast to the above, the advances made to date in the field of fluidic proportional or analog systems is comparatively small. This slow progress is not the result of any lack of motivation for the development of fluidic analog systems. In fact, there exists a need for the development of fluidic system blocks that would perform the functions of currently used electronic analog systems such as operational amplifiers, modulators, etc. Practical development of the fluidic analogs of these electronic systems would permit a more complete replacement of electronic circuitry by the fluidic equivalents in environments where such a replacement is desirable and possible. Rapid development of such fluidic analog systems has been hindered primarily due to the following limitations : (1) limited frequency response and high noise level of proportional fluidic amplifiers and (2) inadequate knowledge about the behaviour of fluidic transmission lines, which are used as the interconnections between elements. The most well known of the proportional devices, namely the beam deflection amplifier, has an upper frequency limit of the order of 1 kHz or less. Furthermore, a great amount of care is necessary in the biasing and interconnection of these elements

to obtain moderate gain with a good signal to noise ratio. The frequency response limitation is caused by effects similar to those which occur in electronic vacuum tubes and transistors at VHF band frequencies. In the latter devices, the bandwidth problem is remedied by analyzing the equivalent circuit of the device at the limiting frequencies and then by attempting to provide proper compensation with the object of nullifying the impedance effects which cause the droop in the H.F. response. This approach has been attempted for the fluidic beam deflection element, for which equivalent circuits have been derived, but suitable compensating schemes are yet to be investigated.[1] The noise problem associated with fluidic proportional elements appears to originate mainly in the jets which form parts of the element. It is recognized that the turbulence produced in these jets is the fluidic equivalent of noise in electron devices. Turbulence has long been a subject of great interest in the field of aerodynamics and as a consequence, most studies in jet turbulence done to date have an aerodynamic background. The consideration of jet turbulence from the point of view of noise in proportional fluidic elements has received comparatively little attention. The value of noise studies in the general development of proportional fluidic systems cannot be over-stated. The transmission line limitation referred to earlier is even more serious than that caused by the frequency and noise performance of the amplifiers alone. In fact, it can be said that in present proportional fluidic circuits, the frequency capability of the amplifiers is not fully utilized mainly because of the attenuation and resonance effects in the interconnecting lines. This behaviour is caused by the fact that fluidic lines begin to act as distributed parameter lines at frequencies which are roughly a million ($10^6$) times lower than those at which similar effects appear in electromagnetic lines. Indeed, there appears to be a close similarity between fluidic and microwave transmission lines,

at least in the problems associated with line matching line resonance. It seems probable that some of these techniques used at microwave frequencies in electromagnetic lines could be used to devise analogous techniques for use with fluid lines. At any rate, an investigation into this approach to fluid line matching problems is highly desired. Although considerable theoretical work has been done on fluidic transmission lines, little information is available on practical line performance and matching techniques for analog signals. Rapid development of fluidic proportional systems will be impossible until a proper understanding of the fluid line is achieved.

In addition to the aforementioned problems there also exists the general problem of transducers for measuring the fluidic proportional systems parameters such as time-varying velocities and pressures. There is a definite need, from the point of view of fluidics research, for the development of such transducers (or sensors) having a wider frequency response and a smaller physical size than currently in use. For turbulence and velocity measurement in fluidics research, the hot-wire anemometer is the only instrument commercially available at present. The hot wire anemometer is indispensable for turbulence measurements, but requires delicate adjustment in order to obtain a large bandwidth and stable operation. It is only very recently that an alternative scheme for measuring turbulence, using aerodynamic lift, has been proposed and investigated.[2] In pressure transducers, the physical dimensions appear to be the main limitation. The various types, such as the capacitive, piezoelectric, strain gauge and magnetic reluctance types, still have to be mounted in a fixture which then acts as a fluidic filter with definite frequency characteristics. The significant dimension of these sensors itself is comparable to the wavelengths encountered, thereby causing non-uniform loading of the sensor

and consequently in inaccurate reading. Apart from sensors, there also exists a need for fluidic signal generators which could generate clean sinusoidal signals over as wide a bandwidth as possible. Several mechanical as well as electrical drive schemes have been used to construct such a generator but have met with problems such as high noise levels and low frequency response. It can be seen from the above that further development is very desirable in area of fluidic transducers also.

## 2. CURRENT RESEARCH PROPOSALS

The proposed research programme of the Fluidics Research Laboratory of the Sir George Williams University directly relates to the research and development problems of proportional fluidic systems indicated in the introduction. The proposed research has been classified broadly into three areas : (1) Turbulence-Noise studies, (2) Transmission line studies and (3) Transducers, with present emphasis being placed on the first named area. Brief outlines of the work proposed in each of these areas follow.

### (1) Turbulence-Noise Studies

The research into this area is aimed towards characterization of turbulence-noise in proportional fluid amplifiers. It is felt that a characterization of jet turbulence in terms of its frequency composition and as a function of the operating jet parameters and measurement location, would be of great value in the design of proportional fluid amplifiers from the point of view of optimizing the signal to noise ratio. In commencement of this programme, work has been started on the measurement of the power spectra and turbulence component intensities of the turbulence from a ½" square jet at various locations facing the jet and as a function of the jet operatingg parameters. It is proposed, at a later date, to also obtain

time and space correlations between the components of [illegible] waveforms at different points with a view to obtain a better estimate of the distribution of noise frequencies.

(2) Transmission Lines

The object of this study is to examine the impedance concepts for fluidic lines and to investigate the problem of impedance matching in fluidic lines carrying analog signals. It is proposed to examine the possibility of using matching techniques analogous to those used for microwave transmission lines. Experimental work in this area has been hindered due to a lack of miniature transducers and of a suitable fluidic signal generator for conducting tests.

(3) Transducers

Research in this area has been directed mainly towards the development of a fluidic signal generator with an electrical input. A fluidic signal generator capable of a clean sine wave output in the range of 0 to about 5 kHz would be extremely useful for tests on, as well as for the operation of, fluidic proportional systems. The system used, at present, for the generation of fluidic sine waves consists of a heavy duty loudspeaker driver equipped with a tapered line which feeds into the fluidic circuit. The response of this system extends to less than a kilohertz although the bandwidth of the driver alone is from 70 to 12,000 Hz. The above effect illustrates well the high frequency attenuation caused by the lines and the entrained volume of the driver. Work is in progress in the design and development of a flapper-valve type signal generator to obtain a noise-free sinusoidal signal over as wide a range of frequencies as possible.

## 3. RESEARCH FACILITIES

The fluidics research laboratory is being established in an independent room with a floorspace of about 24 by 32 feet. The room is equipped with four small office enclosures and a work bench space totalling a length of 18 feet. The work benches are provided with detachable hardboard vertical panels on which the experimental schemes may set up. The panels are being fitted with precision test pressure gauges and flow velocity measuring instruments for the accurate determination of the pressure and steady flow ranges encountered in fluidics. The panels are supplied with filtered air at 20 psig which is then reduced to smaller pressures, according to the requirements, using Nullmatic pressure regulators. A brief list of the instrumentation facilities available for research into the areas mentioned earlier is given below.

| EQUIPMENT | FUNCTION |
|---|---|
| 1) DISA 55D00 Constant Temperature Anemometer System Two DISA 55D05 Battery Operated CTA modules, Two DISA 55D15 Linearizers, plus a variety of hot wire and hot film probes. | Measurement of turbulence intensities, instantaneous flow velocity, simultaneous 2 or 3 channel measurement of turbulence fluctuations over a wide velocity range. |
| 2) Pressure measurement systems. | |
| (a) Pace-Wiemko Magnetic Reluctance Transducer kit Type MP15. | Measurement of steady and fluctuating pressures in fluidic systems. The systems (a) and (b) are capable of being fitted with interchangeable diaphragms to obtain pressure ranges of 1 psig or lower. |
| (b) DISA 55E01 Reactance Converter with capacitive transducers. | |
| (c) Kistler Piezoelectric Transducers Types 602L and 601 and charge amplifiers. | |
| (d) Statham strain-guage transducers Type PM 222 TC. | |
| (e) B and K Type 4133/4134 Condenser microphone with associated equipment (For acoustic pressures) plus standard test gauges and precision manometers | |

3) DISA Analog Correlator Type 55D7C.

4) B and K Type 2107 Frequency Spectrum Analyzer, and the B and K Type 2305 level recorder.

5) HP-Sanborn Type 3900 Magnetic Tape Recording system.

Correlation and power spectral analysis of Turbulence noise, Simulation of fluidic systems.

6) Elgenco 632A Gaussian Noise source.

7) EAI 680 Hybrid Computing System.

8) Digital Computing facilities of the Sir George Williams University ComputerCenter.

9) Facilities of the Mechanical Engineering and Systems Engineering Laboratories.

10) Excellent Machine Shop facilities with three experienced precision machinists available for component fabrication.

General purposes.

## REFERENCES


(A)

1. Besterling, C.A. and Tsui, K. : "Analyzing Proportional Amplifier Circuits", Control Engineering, August 1965, pp. 87-92.

2. Siddon, T.E. : "A Turbulence Probe utilizing aerodynamic lift", UTIAS Technical Note No. 88, June 1965, (University of Toronto), Institute for Aerospace studies.

(B) GENERAL

3. Bowles, R.E. and Dexter, E.M. : "Components for FM and AM Fluidic Circuits", 2nd Cranfield Fluidics Conference, Paper D5, January 1967, Cambridge (U.K.).



Prepared by: N. Suresh
Research Associate


April 1, 1968

# APPENDIX C

SIR GEORGE WILLIAMS UNIVERSITY

MONTREAL 25, CANADA

11th April, 1968.

F. M. Hanna,
Chief Engineer,
Research Development,
Aviation Electric Ltd.
P.O. Box 2140,
St. Laurent,
Montreal 9, P.Q.

Support of Fluidics Research at Sir George Williams University

Dear Mr. Hanna,

Further to our telephone discussions and your letter of March 13, 1968, we hereby request support in the amount of $15,300 for 1968/69 which is required to ensure continuity of our existing Fluidics Research program.

Appendix A defines the activities of the Fluidics research group and the supporting facilities at Sir George Williams University. It shows:

1. That work is being done in two major research areas, namely:
   a) Investigation of turbulent noise in fluidic devices;
   b) Transmission line modelling and matching.

2. That a major commitment in facilities has been made in the fluidics area, namely, provision of:
   a) A separate laboratory for fluidics research.
   b) A wide range of the necessary research equipment and instrumentation.
   c) Four furnished offices for fluidics research personnel.
   d) Other research services, such as digital and analog computers, machine shop and library.

Appendix B identifies the personnel working in the fluidics group as follows:
Three full-time faculty members, two full-time research associates, one half-time research assistant, possibly a number of graduate students wihhin a year; other personnel providing services as required areAmong Simulation engineer (analog programmer).

digital computer personnel, and three machinists, two technicians (one electrical, one mechanical).

Appendix C points out that the undergraduate curriculum at Sir George Williams University has considerable systems emphasis and that the graduate program has a range of courses for students interested in fluidics. It is noted that approximately 10 students have selected to take the "Fluidics" graduate course as part of their M.Eng. program.

Further support of the fluidics research program is needed in several ways and it is hoped that NRC through Aviation Electric Limited can contribute towards the salaries of research personnel as indicated abelow.

| | |
|---|---|
| a) 1/2 of full-time salary of N. Sureah .. .. .. | $ 4,400 |
| b) 1/2 of full-time salary of John Vrana (or his replacement) .. | 4,400 |
| c) 1/2 of salary of Research assistant, Siemer Tsang | 3,000 |
| d) 2 months salary for faculty members supervising project .. | 3,000 |
| e) Miscellaneous .. .. .. .. .. .. .. | 500 |
| | $14,300 |

The remainder of the salaries for personnel will be paid by the University funds and NRC operating grants to faculty members.

Questions with respect to submission of reports, propriety interests, patents and publications will of course have to be discussed and agreed upon.

Yours very truly,

J. C. Gallaghan

M. P. du Plessis.

MPdeP/ej

200 LAURENTIEN BLVD., MONTREAL, CANADA • TELEPHONE: 744-2811
Cables: AVIATION, MONTREAL

AVIATION ELECTRIC
LIMITED

Mail Address: P.O. BOX 2140, ST. LAURENT
MONTREAL 9, P.Q.

March 13, 1968

Mr. C. Callaghan
Sir George Williams University
1435 Drummond
Montreal, Quebec

Dear Mr. Callaghan:

As discussed by telephone we enclose a copy of the reply from NRC concerning our inquiry about sponsoring Fluidics Research in universities. You will note the conditions imposed by NRC which we believe can be met, with the exception that less than 100% of the time of your staff will be spent at A.E.L.

As agreed, the responsibility for preparing the submission is yours. However we shall discuss the details with you and submit it to NRC with a covering letter after approval by us.

Yours very truly,

F.M. Hanna
Chief Engineer
Research and Development

FMH:fn
Encl.

CABLE ADDRESS
ADRESSE TÉLÉGRAPHIQUE "RESEARCH"

PLEASE QUOTE FILE NO
NO DE DOSSIER À MENTIONNER 53-3A-15

RECEIVED
JAN 2 1968
Ans'd.

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

OTTAWA 7.

Ref SCW's application

January 15, 1968.

Mr. E. Wall, Vice-President,
Engineering & Sales,
Aviation Electric Limited,
P.O. Box 2140, St. Laurent,
MONTREAL 9, Quebec.

Dear Mr. Wall:

In considering ways and means of fulfilling its terms of reference, which require it to provide financial assistance to establish competent research teams in Canadian industry, the I.R.A. Committee feels that one way of upgrading the competence of industrial teams is to support the participation of university professors in I.R.A. projects.

Young, inexperienced teams could be helped considerably by the guidance and advice of experienced research personnel from universities in developing their personal and team capabilities, and in their approach to and programming of the research projects.

More experienced teams, because of the concentrated nature of product-oriented industrial research and the more narrow approach involved, tend to become specialists in certain areas. Accordingly, they may lack experience in areas of increasing importance to their work, and may lose touch with the broader perspectives in their research field and progress being made in other disciplines affecting their field. They would benefit from direct exposure to the thoughts and experience of well-qualified university professors.

On the other hand university professors can gain from direct contact with the requirements and the problems of industrial research in which many of their students will seek careers, and, perhaps, the opportunity to use special equipment in company laboratories. Through such contacts, a useful feedback to the universities would be established which could have an influence upon the nature and scope of university training and research, to the mutual benefit of the universities, their graduates, industry and the Canadian economy as a whole.

. . . . . 2

Many companies and university professors already have discussed informally such relationships and representatives of industry and universities with whom this type of support has been discussed have endorsed it enthusiastically. The Committee itself has supported such arrangements in a few specific cases and, in broadening their application to all projects in I. R. A. P., feels that it will create better communication and co-operation between industrial scientists and university scientists in the same way that I. R. A. P. has improved such relationships between Government and industrial scientists.

Accordingly the Committee will consider applications from companies for support of professors from the staffs of Canadian universities to be employed on I. R. A. P. projects within the following general guide lines:

(a) The work must be directly related to an I. R. A. project and performed in the company laboratories in close and regular contact with the I. R. A. supported team.

It may comprise direct participation in the laboratory work as part of or in association with the company team, or take the form of seminars, informal discussion groups and similar instructional activities to provide an exchange of knowledge and experience between the professor and the research team.

(b) Employment of a professor for the duration of a sabbatical year, for several months in the summer, or other similar periods of leave from university responsibilities would qualify. Alternatively, employment for a specific number of days during a year on a regular basis, such as one day per week or per month for example, would qualify.

Employment of a professor on an irregular or ad hoc basis as a consultant to solve a specific problem, the solution of which is the only and immediate purpose of his employment, would not qualify. Such research or advice may be essential to bring the project to a successful conclusion but it does not necessarily contribute to the establishment of a competent research team. Hence it is considered to be the financial responsibility of the company.

(c) More than one professor may be employed on a project, providing the salaries do not exceed the financial limitation approved by the National Research Council.

(d) I. R. A. P. will reimburse the company for the salary portion of the professor's fee. All travel, accommodation and other expenses connected with his employment are to be paid by the company.

Companies may apply for such assistance in their original proposal, in their yearly renewal, or as a supplementary grant during the fiscal year. Application forms may be obtained from the Secretary of the I. R. A. Committee, which will require a summary of the professor's qualifications and experience, details of the agreement between the company and the professor, and a statement from the company as to the nature and purpose of the professor's participation.

The Committee will consider each case on its merits, bearing in mind the value of the professor's services associated to the objectives outlined above, the need to avoid interference with the academic responsibilities of university staff and their research work under other research grants, and, of course, the availability of funds. The latter factor may limit this type of support considerably during the fiscal year 1968/69.

In considering introduction of university staff into I. R.A. projects, companies may find it advisable to consult the Head of the University Department concerned as to the suitability of personnel, and to avoid an uneven distribution of these activities among the professorial staff.

Yours very truly,

R.E. McBurney

R. E. McBurney, Secretary
NRC Committee on Industrial Research Assistance.

REM:FB

# APPENDIX D

DIVISION OF MECHANICAL ENGINEERING
DIVISION DE GÉNIE MÉCANIQUE

CABLE ADDRESS
ADRESSE TÉLÉGRAPHIQUE
"RESEARCH"

PLEASE QUOTE FILE No. M2-17-1[illegible]-13

THE DR. ROOBIK A. RAFFELEY

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

OTTAWA 7. January 29, 1968.

Mr. J.C. Callaghan,
Associate Professor,
Faculty of Engineering,
Sir George Williams University,
Montreal 25, Quebec.

Dear Clair:

Thank you for your letter of January 18, 1968 with the enclosed brochures on the strain gauge pressure transducers which look very attractive.

Further to our conversation regarding the possibility of a member of your fluidics group working in the Mechanical Engineering Division at N.R.C. for a specified period in the capacity of a visiting Engineer, Dr. J.A. Tanner, head of the Control Systems Laboratory, has expressed his wholehearted agreement for such an arrangement. The duration of such a visitation period would be at the discretion of your organisation, although a minimum period of a number of weeks might be preferable.

Regulations would necessitate the sponsoring organization, in this case Sir George Williams University, to absorb remuneration expenses for the visiting Engineer. N.R.C. would provide all necessary working facilities including office space, laboratory facilities, computer access, technician support, etc. It is anticipated that by April 1968 the fluidics laboratory facility with associated instrumentation will be operational and the experimental portion of the fluidics systems program initiated. The fluidic fabrication program, which we discussed briefly during your visit, will also be continuing with prototype manufacturing capability hopefully being available in the spring. Interested candidates could either become involved in the currently active NRC fluidic programs or they could carry out separate studies at their preference.

Such an arrangement would appear to be very attractive in introducing the technology in both its theoretical and practical aspects to persons who intend to become directly involved in your fluidics programs. N.R.C. would in turn benefit from the closer liaison with Sir George Williams in general and with the fluidics activities there in particular.

.../ 2

Should any further information be required regarding such a possible arrangement, do not hesitate to call me at 613-993-9295.

Yours sincerely,

Bill Mayes

W.J. Mayes
Control Systems Laboratory

WJM/pt

# APPENDIX F

# MAJOR JOURNALS AND PUBLICATIONS IN FLUIDS, CONTROLS AND INSTRUMENTATION

| | | |
|---|---|---|
| | Automatica (International Journal) (U.S.A.) | (1967 - ) |
| * | Automatik (Germany) | |
| * | Automatika (Yugoslave professional Journal for Automation) | |
| | Automation (France) | (1967 - ) |
| | Automation (U.S.A.) | (1967 - ) |
| * | Automation and Remote Control (English translation of Automatika I Telemekhanika) | |
| * | Automatisme (France) | |
| * | Automazione E Automatismi (Italy) | |
| * | Acta Mechanica (Austria) | |
| | AIAA Journal | (1963 - ) |
| | Acoustical Society of America (1929-1959 on microfilm) | (196) - with gaps) |
| | Aeronautical Quarterly | (1960 - with gaps) |
| | ASME (Transactions) (on microfilm) | (1888-1929) |
| | ASME (Transactions) (Bound volumes) | (1930- ) |
| | A C M Journal (U.S.A.) | (1960 - ) |
| | Applied Scientific Research | (1947 - with gaps) |
| | A I E E Transactions | (1902 - with gaps) |
| | Astronautica Acta | (1965 - ) |
| | Astronautics and Aeronautics | (1963 - ) |
| * | Aeronautica Acta | |
| | Batelle Technical Review | (1950 - with gaps) |
| | Bibliography Fluidic System (Bowles Eng.) | (1968 - ) |
| | Communications of the ACM (U.S.A.) | (1960 - with gaps) |
| | Control (Britain) | (1960 - with gaps) |

* not in library

| | | |
|---|---|---|
| | Control Engineering (U.S.A.) | (1954 - with gaps) |
| * | Cybernetics (English translation of Kibernetika) (U.S.A.) | |
| | Cybernetica | (1958 - ) |
| * | Canadian Controls and Instrumentation (Canada) | |
| * | Computer Design (U.S.A.) | |
| | Computers and Automation (U.S.A.) | (1960 - with gaps) |
| | Canadian Aeronautics and Space Journal | (1955 - with gaps) |
| | Design Engineering (Canada) | (1959 - ) |
| * | Data-Trend (Australia) | |
| * | Data and Control Systems (England) | |
| | Data Systems | (1968 - ) |
| | Electromechanical Design | (1967 - ) |
| * | Electronic Instruments Digest (U.S.A.) | |
| | Electronic Engineering (Great Britain) | (1967 - ) |
| * | Electromechanical Components and Systems Design (U.S.A.) | |
| | Electromechanical Design | (1967 - ) |
| | Fluidics Quarterly | (1968 - ) |
| | Fluid Power International | (1967 - ) |
| | Fluidics Quarterly | (1968 - ) |
| | Hydraulic Pneumatic Power (England) | (1967 - ) |
| | Hydraulics and Pneumatics (U.S.A.) | (1967 - ) |
| * | Hydraulique, Pneumatique and Asservissements (France) | |
| * | IFAC : International Federation of Automatic Control Information Bulletin | |
| | Information and Control (U.S.A.) | (1965 - ) |
| * | International Control Equipment (Britain) | |
| | International Journal of Control | (1965 - ) |

* not in library

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|---|---|---|
| | I B M Journal of Research and Development | (1957 - ) |
| | International Journal of Heat and Mass Transfer | (1960 - with gaps) |
| * | International Association for Analog Computation Proceedings (Belgium) | |
| | International Association of Analog Computation Annales | (1967 - ) |
| | I.S.A. Transactions (U.S.A.) | (1967 - ) |
| * | Instrument Engineer | |
| | Instrument Practice (England) | (1967 - ) |
| * | Instrumentation (U.S.A.) | |
| | Instrumentation Technology (U.S.A.) | (1955 - with gaps) |
| | Instruments and Control Technology (U.S.A.) | (1959 - with gaps) |
| | I.E.E.E. Transactions on Automatic Control (U.S.A.) | |
| | I.E.E.E. (Sonics and Ultrasonics) | (1964 - ) |
| | I R E Transactions on Automatic Control (U.S.A.) | (1963 - ) |
| * | I.E.E. Transactions (U.S.A.) | |
| * | Instruments of Mechanical Engineering Proceedings (U.S.A.) | |
| | Instruments and Experimental Techniques (U.S.A.) | (1966 - ) |
| | International Science and Technology | (1962 - ) |
| | International Association for Analog Computation Proceedings | (1967 - ) |
| | Journal of Fluid Mechanics (U.S.A.) | (1966 - ) |
| | Journal of Franklin Institute(U.S.A.) | (1960 - ) |
| * | Journal of Aeronautic Science | |
| | Journal of Electronics and Control (Great Britain) | (1960-1963) |
| | Journal of Scientific Instruments (Great Britain) | (1952 - ) |
| | Journal of Photographic Science | (1967 - ) |
| | Journal of Spacecraft and Rockets | (1967 - ) |

* not in library

| | | |
|---|---|---|
| | Journal of Astronautical Sciences | (1955 - with gaps) |
| | Journal of Applied Mathematics and Mechanics | (1958 - ) |
| * | Journal Instrument Society of America | |
| | Journal of Applied Physics | (1950 - ) |
| | Journal of Scientific Instruments | (1952 - with gaps) |
| * | U.S. N B S Journal of Research Sect. A. Physics and Chemistry | (1965 - ) |
| * | U.S. N B S Journal of Research Section B - Mathematics and Mathematical Physics | (1965 - ) |
| * | U.S. N B S Journal of Research Section C - Engineering and Instrumentation | (1959 - ) |
| * | Kybernetik (U.S.A.) | |
| * | Mesures, Regulation, Automatisme (France) | |
| | Machine Design (U.S.A.) | (1955 - with gaps) |
| | Measurement and Control | (1967 - ) |
| | Mechanical Engineering | (1921 - with gaps) |
| * | New Equipment News (Canada) | (1940 - ) |
| * | New Equipment Digest (U.S.A.) | (1936 - ) |
| | Operations Research (U.S.A.) (Vol. 7) | (1959 - ) |
| | Operations Research (U.S.A.) (Vol. 1 - 7) | |
| | Process Control and Automation (See Instrument Practice) (England) | (1967 - ) |
| | Proceedings of National Electronics Conference (U.S.A.) (Vol. 19, 22 & 23) | |
| | Product Design and Engineering | (1961 - ) |
| | Product Engineering | (1967 - ) |
| | Progress in Control Engineering | (1962 - 1964) |
| | Purdue University, School of Aeronautical and Engineering Sciences | (1967 - ) |

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|---|---|---|
| | Proceedings Inst. of Physics and Physical Society | (1935 - with gaps) |
| | Proceedings Royal Society of London, Series A : Mathematical and Physical Sciences | (1923 - with gaps) |
| | Progress in Aeronautical Sciences | (1961-1962, 1964-1967) |
| | Progress in Astronautics and Aeronautics (Vols 1-2, 4-7, 9-12, 14-18) | |
| | Progress in Automation, Vol. 1 - | |
| | Progress in Materials Science | (1949 - ) |
| | Review of Scientific Instruments | (1933 - with gaps) |
| | Royal Aeronautical Society Journal | (1927 - ) |
| * | Soviet Fluid Mechanics (U.S.A.) | |
| | Space/Aeronautics | (1961 - ) |
| | Sperry Engineering Review | (1963 - ) |
| | The Physics of Fluids (Journal) | (1958 - with gaps) |
| | Transactions of the Society of Instrument Technology | (1967 - , 1960-1966 |
| | Technical Notes of the National Bureau of Standards (No. 185) | |
| | United States N.B.S. Technical News Bulleting | (1950 - ) |
| | Siam Journal on Applied Mathematics | (1967 - ) |
| * | Siam Journal on Numerical Analysis | |
| * | Siam Review | |
| * | Theory of Probability and Its Applications (Siam Publication) | |
| | Siam Journal on Control | (1967 - ) |

* not in library